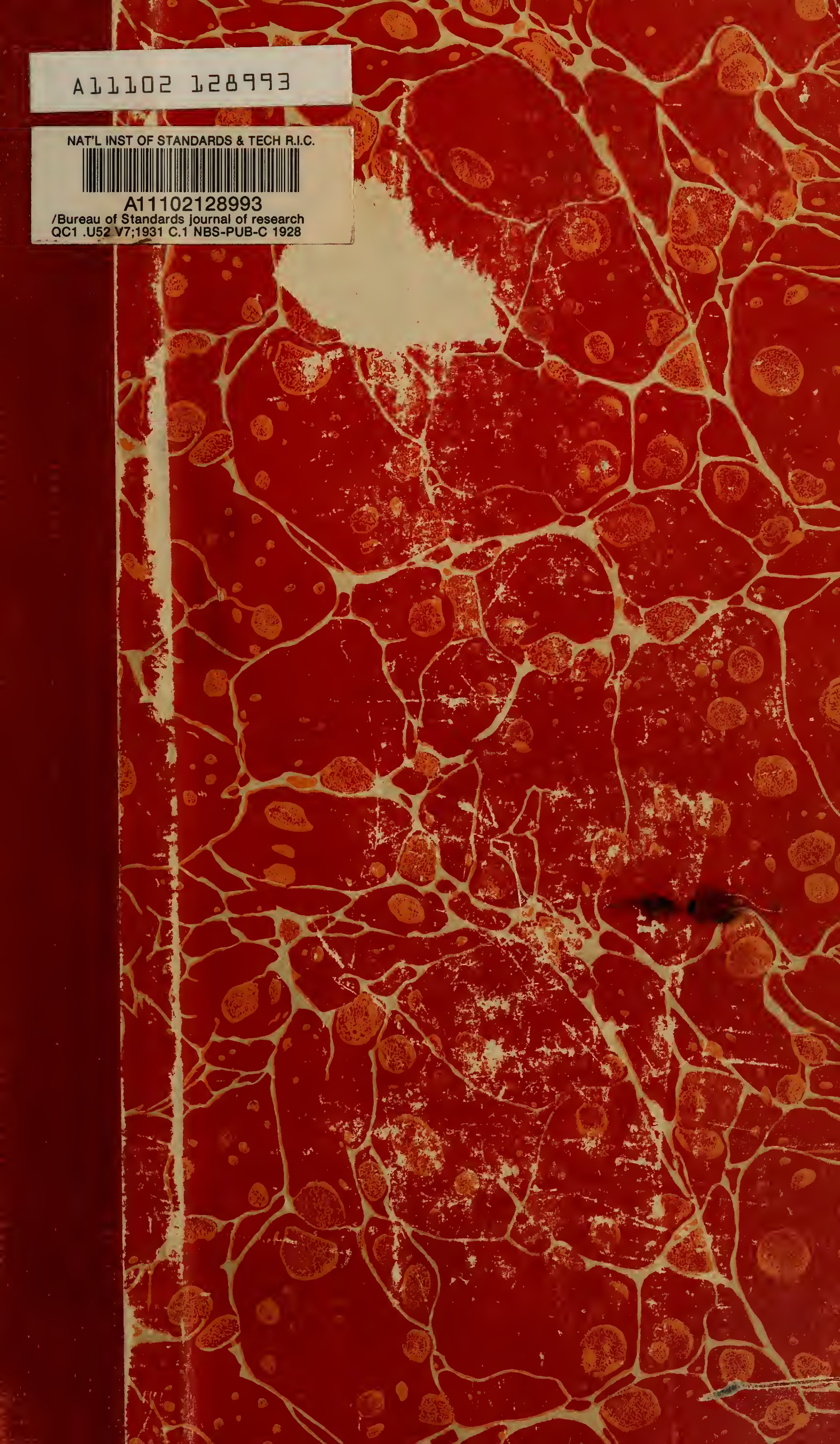

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CORRELATION OF CERTAIN SOIL CHARACTERISTICS WITH PIPE-LINE CORROSION

By I. A. Denison

ABSTRACT

Corrosion which has been experienced on a group of pipe lines in Ohio is attributed to the corrosiveness of certain soils occurring along the lines. Areas occupied by different soils correspond in a general way to corrosive and noncorrosive areas, as shown by a record of pipe replacements over a period of years. The most corrosive areas are occupied by heavy, acid soils which have developed from glacial material. The chief factors influencing the corrosiveness of the soils are acidity, texture, and drainage. Values for total acidity of soil samples taken at various points along the lines indicated in a satisfactory manner the areas differing in corrosiveness. These areas were also indicated by pH values of the soil extracts in normal potassium chloride solution. An accelerated test of the relative corrosiveness of soils is described. The results of this test, which is based on the corrosion of a steel disk in contact with moist soil, agreed in general with the results of the acidity tests in defining the corrosive areas.

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I. INTRODUCTION

The experience of pipe-line operators has shown that pipe lines may be severely corroded in localities where corrosion can not be ascribed to stray electric current, corrosive liquors, or to other well-recognized causes of corrosion. In such areas it would seem that the causes of corrosion must be sought in the inherent characteristics of the soils in which the pipe lines are laid. The importance of studying the relations between soil characteristics and corrosion has been emphasized by the results obtained with buried specimens of pipe in the original soil-corrosion investigation of the National Bureau of Standards. Supplementing this investigation the bureau has on several occasions undertaken the study of corrosion experienced in the operation of pipe lines. This method tends to complicate the study of soil corrosion, for the reason that pipe-line currents in certain areas may possibly accelerate or reduce the corrosion which would occur if the pipe were unconnected. It has a certain advantage, however, in that the long periods during which certain lines have been in operation have tended to minimize the effect of variations in such factors as climate and quality of pipe materials, and also the influence of temporary local conditions which might obscure the inherent corrosiveness of the soil.

A study of soil corrosion was made during 1929–30 on a group of pipe lines to determine whether corrosion is confined to certain soils occurring along the lines or whether it is induced more by local conditions than by kind of soil. A second object of the study was to define, if possible, those characteristics of the soils which seemed to influence corrosion, with the view of applying the results obtained to the development of methods for determining soil corrosiveness. This study was made possible by the fact that the company operating the lines has kept a detailed record of all leaks and pipe replacements since the lines were installed, which was, in the case of the oldest line, more than 40 years ago. Quantitative expressions for the corrosion which has occurred at various points on the lines were, therefore, available for comparison with soil conditions and with the results of laboratory studies.

The field work in this investigation was carried out on a 32-mile section of a group of pipe lines in Ohio. The lines run parallel at an average distance of 1 foot apart, and from 18 to 24 inches below the surface. Corrosion has not been general over the lines, but has occurred chiefly in restricted areas. In certain sections several thousand feet of pipe have been replaced two and three times; in other sections, however, no replacements have been made in over 40 years. The individual lines also show great variation in the extent to which they have been replaced, one line in particular having required but few replacements in certain areas where the other lines have been rather severely corroded.

The soils occurring in the area studied were derived from both glacial and lacustrine (lake-laid) material. The chief glacial soils are those of the Brookston and Nappanee series. These soils are closely associated, the latter often occupying the slopes in regions where the level areas are occupied by the Brookston soils. Owing to their somewhat exposed position the Nappanee soils have been more highly weathered than the Brookston soils, as shown by their lighter color and their heavy acid subsoil. Soils of both series are poorly drained. The lacustrine soils are, in general, much coarser in texture than the glacial soils and are usually fairly well drained. Since little corrosion has been experienced in these soils, it was considered sufficient for this study to consider the lake-laid soils as a single group. Several series, however, were recognized, namely, the Plainfield, Newton, Fox, Berrien, Lucas, Toledo, and Fulton series. Intermediate between the glacial and lacustrine soils are those of the Wauseon series, which are sandy loam soils overlying heavy glacial material at a depth usually between 20 and 30 inches.

II. RELATION BETWEEN SOIL SERIES AND CORROSION

The procedure followed in carrying out the study was first to identify the various soil series occurring along the lines and to fix their boundaries by stake number.[1] The relation obtaining between corrosion and soil series was then studied by plotting the average percentages of pipe replaced in 1,000-foot intervals along the lines, indicating on the diagram the boundaries of the soil series present. At a number of locations samples of virgin soil were taken at pipe depth for study in the laboratory of those factors which appeared to influence corrosion.

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[1] The writer wishes to acknowledge his indebtedness to Dr. G. W. Conrey, of the Ohio agricultural experiment station, for assistance in identifying the soils.

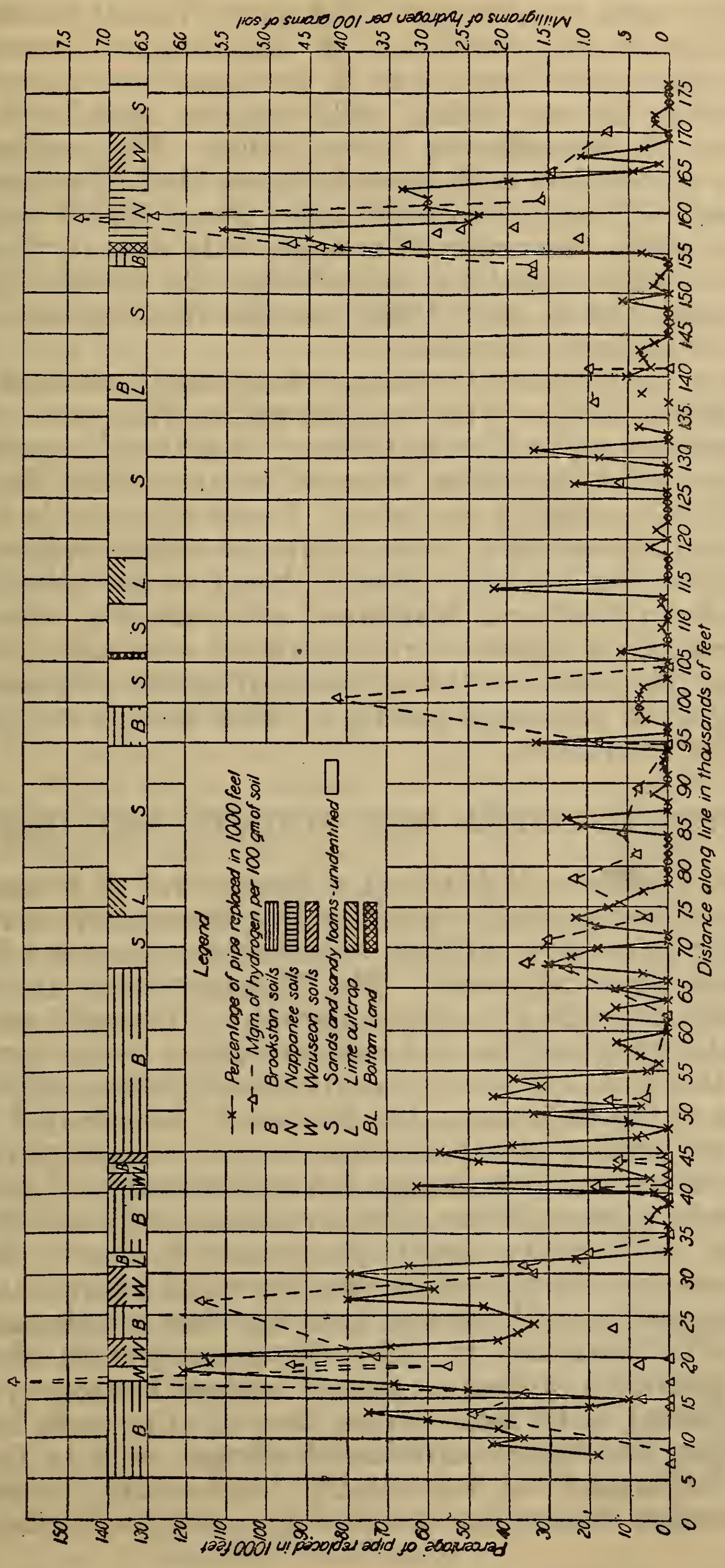

FIGURE 1.—*Comparison of values for exchangeable hydrogen in soils, and of soil series with quantity of pipe replaced in intervals of 1,000 feet*

Comparison of the areas differing in corrosiveness with the areas occupied by the various soils indicates a general relation between soil series and corrosion. This relation is brought out in Figure 1. The total acidity values also shown in this diagram will be referred to in a later connection. It can be seen from the figure that the Brookston soils wherever they occur are relatively noncorrosive. The Nappanee soils, on the other hand, are seen to be corrosive wherever they were encountered. Similarly, it will be noted that the areas of sandy loam soils and of lime outcrop correspond to relatively noncorrosive areas. At a few locations corrosion was evidently due to factors which could not be considered inherent characteristics of the soils at these points. No relation would, therefore, be expected in such areas between kind of soil and extent of replacement. Thus, between the stake Nos. 113,000 and 114,000, the corrosion which has occurred is apparently due to the presence of cinders from a lime plant now abandoned. In certain other areas, such as between 12,000 and 13,000, location of the pipes in ditches would explain the local corrosion.

An exception to the general relation between soil series and corrosion is to be noted in the case of the soil mapped as Wauseon. It will be noted that between stake Nos. 18,000 and 22,000 and between 26,000 and 31,000 this soil is corrosive, whereas between stake Nos. 165,000 and 170,000 it is but slightly corrosive. It was observed in comparing these areas that the corrosive areas occupy two slight ridges; whereas the noncorrosive area is level. This relation was also observed in the case of the Brookston and Nappanee soils, namely, that marked corrosion occurred on slopes whereas the level areas are noncorrosive. The greater corrosiveness of the soils occupying the ridges and slopes is to be ascribed to the higher acidity of these soils as compared with the soils of the level areas.

III. RELATION BETWEEN SOIL ACIDITY AND CORROSION

The essential difference between the corrosive and noncorrosive soils in this area is apparently one of acidity, the noncorrosive Brookston soils being neutral or alkaline; whereas the corrosive Nappanee soils are characteristically acid. The Wauseon soils may be either acid or alkaline depending on the topography. It would seem, therefore, that soil acidity may be an important factor in the corrosion experienced in this area, and that a quantitative expression of the relative corrosiveness of the soils along the line would be afforded by determination of the acidity of soil samples taken at various points.

Although values for the hydrogen ion concentration of soil extracts may indicate in a general way whether certain soils are likely to be corrosive, the total acidity would be expected to show a closer relationship to corrosion for the reason that the total acidity includes not only the concentration of hydrogen ions, but that of unionized hydrogen as well. In those soils in which the concentration of unionized hydrogen is greatly in excess of that of ionized hydrogen, corrosion would be expected to be more severe than in other soils having the same pH value, but which contained hydrogen only in the ionized form. The importance of determining total acidity in connection with soil corrosion studies has been recognized by both Shipley[2] and Holler.[3]

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[2] Shipley, J. W., McHaffie, I. R., and Clare, N. D., Corrosion of Iron in Absence of Oxygen, Jr. Ind. Eng. Chem., vol. 17, pp. 381-385; 1925.

[3] Holler, H. D., Corrosiveness of soils with respect to iron and steel, J. Ind. Eng. Chem., vol. 21, pp. 750-764; 1929.

A method which has been used to determine the total acidity of soils is the electrometric titration of suspensions of soil in water. This method was employed by Holler in his studies of the relation between the total acidity of soils and their corrosiveness. One of the chief defects of the method of direct titration of soil suspensions is that alkali is consumed by soils as the result of effects other than neutralization. This was recognized by Holler in the work mentioned. Addition of alkali to soils beyond the point of neutralization appears to result in direct absorption of the alkali, in much the same manner that animal charcoal, activated silica, and other absorbents devoid of acidic hydrogen are able to absorb basic ions. Since the transition between complete neutralization and alkali absorption by soils can seldom be recognized with certainty owing to the smoothness of the usual titration curve, determinations of total replaceable hydrogen by this method are necessarily somewhat arbitrary and inaccurate.

An alternate method for estimating the total acidity of soils by which effects other than neutralization may be avoided consists in removal of ionic hydrogen from the soil by extraction with a neutral salt solution and titration of the extract obtained. Methods involving this principle have been employed by Parker,[4] by Schollenberger and Dreibelbis[5] and others. These methods depend on the fact that hydrogen ion adsorbed by the colloidal material of the soil can be replaced by the basic ion of a salt solution, the completeness of the replacement depending primarily on the nature of the salt used. Since at least a part of the adsorbed hydrogen is very slightly dissociated it is apparent that fairly complete replacement can be obtained only when the concentration of hydrogen ions in the extracting solution is maintained at a minimum. This may be accomplished by the use of a highly buffered solution and by continuous removal of the solution after it has reacted with the soil. Although complete removal may not be accomplished by the procedure of extraction, it is likely that measurement of the readily replaceable hydrogen may more nearly represent that part of the total adsorbed hydrogen which is active in underground corrosion than values for the total hydrogen present in the soil. Whether this assumption is valid, however, can not be stated at this time.

A normal solution of barium acetate was used for extracting the adsorbed hydrogen. Before use the normally alkaline solution was adjusted to "neutrality" (pH 7) with acetic acid in order to minimize the adsorption of hydroxyl ions which, as has already been pointed out, is likely to occur in the case of highly absorptive soils. It is probable, however, that barium acetate solution adjusted to about pH 8.3, at which point phenolphthalein shows a sharp color change, would give equally satisfactory extractions and would involve less uncertainty in the titrations through the magnitude of the blank correction otherwise required. This conclusion has been partially confirmed, since completion of the present study, by comparing the values obtained using barium acetate adjusted to pH 8.3 with those obtained with a neutral solution. However, somewhat higher values were obtained by use of the alkaline solution.

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[4] Parker, F. W., Methods for Determination of the Amount and Avidity of Exchangeable Hydrogen in Soils, Proc. and Papers of the First Internat. Cong. of Soil Sci., vol. 2, pp. 164–173; 1928.

[5] Schollenberger, C. J., and Dreibelbis, F. R., Analytical Methods in Base Exchange Investigations in Soils, Soil Sci., vol. 30, No. 3, pp. 161–173; 1930.

Titration of the extract was made with phenolphthalein as the indicator. Although the extract was highly buffered a sharp end point was obtained. Titration of several extracts by a differential potentiometric method showed that the end point coincided with the color change of phenolphthalein. Since the barium acetate solution was initially adjusted to neutrality it was necessary to deduct from the titration value the quantity of alkali required to bring the same volume of neutral barium acetate to the color change of phenolphthalein.

The details of the original procedure were as follows: A 50 g sample of soil contained on a 15 cm filter paper was extracted with normal barium acetate solution, which had been adjusted to pH 7, until 100 ml of the solution after having percolated through the soil showed no change in acidity on titration with 0.1 *N* barium hydroxide. Usually 1 liter of solution was required for complete extraction. In determing the acidity of the extracts, 250 ml aliquots were titrated with 0.1 *N* barium hydroxide to the first definite color change of phenolphthalein. From this titration value was subtracted the volume (approximately 12 ml) of 0.1 *N* alkali required to bring 250 ml of the neutral barium acetate solution to the end point of phenolphthalein.

The quantity of exchangeable hydrogen in the soils at various points along the lines is shown graphically in Figure 1. Comparison of these values with the average percentage pipe replacement of the five lines between intervals of 1,000 feet shows that a general correlation obtains between corrosion and total acidity. In the very corrosive areas between stake Nos. 16,000 and 31,000 and between 156,000 and 164,000 the soils show the highest values for acidity. In certain other areas where few replacements have been made the soils are but slightly acid if at all. In comparing further the data on acidity and replacements it is necessary to take into account the fact previously referred to, that in certain areas replacements have been made necessary by certain incidental factors which are either external to the soil or which were not evaluated by the method used. The lack of correspondence between acidity and replacement between stake Nos. 100,000 and 101,000 would indicate that in this region well drained but highly acid sandy soils are probably not corrosive.

Although the values for acidity may be considered to define the most corrosive areas in a fairly satisfactory manner, it is evident that in small areas of acid soils, the soil at pipe depth frequently shows little if any acidity, indicating a relatively noncorrosive condition. Whether or not marked corrosion has occurred at such points can not be determined, of course, from the replacement data since these data represent the average corrosion which has occurred over intervals of 1,000 feet in which several small noncorrosive areas may occur. In order that the actual corrosiveness of similar areas might not be obscured by variations in acidity at isolated points within the area, it would seem preferable to collect samples of soil from the same stratum or horizon of the soil profile rather than arbitrarily at pipe depth. This procedure would insure that samples of similar soil material would be tested and would probably decrease the number of samples necessary to represent the area.

In testing the corrosiveness of acid soils it is often an advantage to employ methods adapted to the rapid estimation of acidity in the field. Such methods are of especial value in connection with corrosion surveys prior to pipe-line construction. Since the hydrogen ion concentration of soils in a neutral salt solution is related in a general way to the total acidity as was recognized by Holler, this relation if sufficiently close in the case of the soils under study would permit the use of an alternate method for indicating soil corrosiveness.

The relation which obtains between the total acidity of soils and the pH values of these neutral salt extracts, depends upon the fact that the basic ion of a neutral salt is able to replace ionic hydrogen present in an adsorbed condition in acid soils with the result that the H ion concentration of the extract is increased in proportion to the quantity of H ions replaced. Several factors, such as ease or difficulty of replacement, render this proportionality somewhat inexact. However, in soils which do not differ fundamentally in their characteristics apart from degree of acidity a fairly satisfactory relation between the pH values of the soils in a neutral salt solution and their values for total acidity may be expected. The nature of this relation in the soils under test was studied by plotting the pH values of the soils, determined colorimetrically in normal potassium chloride extracts, against the corresponding values for total acidity. The data are shown graphically in Figure 2.

It will be seen from the figure that the pH values in potassium chloride are fairly closely related to the total acidity of the samples except, of course, in the case of the slightly buffered sands indicated on the diagram by the letter S. In view of this relation, the hydrogen ion concentrations of the potassium chloride extracts should define the corrosive areas along the lines about as well as the total acidity. A figure prepared by plotting these pH values with the average percentage replacement between 1,000-foot intervals showed that this method indicated the corrosive areas about as well as the total acidity method. In areas of well-drained sandy soils, which are generally noncorrosive, the acidity values by either method possess little significance.

IV. RELATION BETWEEN CORROSION LOSSES FROM AN ACCELERATED CORROSION TEST AND CORROSION OF PIPE LINES

Soils which are inherently corrosive toward pipe materials might be expected to produce degrees of corrosion in the laboratory which would bear some relation to their actual corrosiveness in the field. This assumption is the basis of an accelerated test for soil corrosiveness which has been devised by V. A. Grodsky, research associate of the Cast Iron Pipe Research Association, at the National Bureau of Standards. This test, which has been studied in a general way only, was employed in the present investigation to bring out certain of the factors on which the test depends. The data obtained are reported at this time merely because they are in general agreement with the data obtained from the acidity determinations and with the record of pipe replacements.

The method consists in determining the extent to which a steel disk is corroded in moist soil in a period of two weeks. The disk used was cut from cold-rolled sheet steel 0.1 mm (0.004 inch) in thickness, and was of such a size as to fit exactly when placed in a straight-side crystallizing dish about 44 mm (1¾ inches) in diameter. The bottom of the crystallizing dish was covered with a sheet of filter paper over which was spread a thin layer of soil. After moistening the soil with ½ to 1 ml of water, the previously weighed disk was placed in the dish, and covered with 10 g of soil which had passed a 2 mm sieve. The soil was compacted by rotating on the surface a solid brass cylinder weighing about 500 g. A piece of filter paper was then placed on the soil and the soil was moistened with a definite

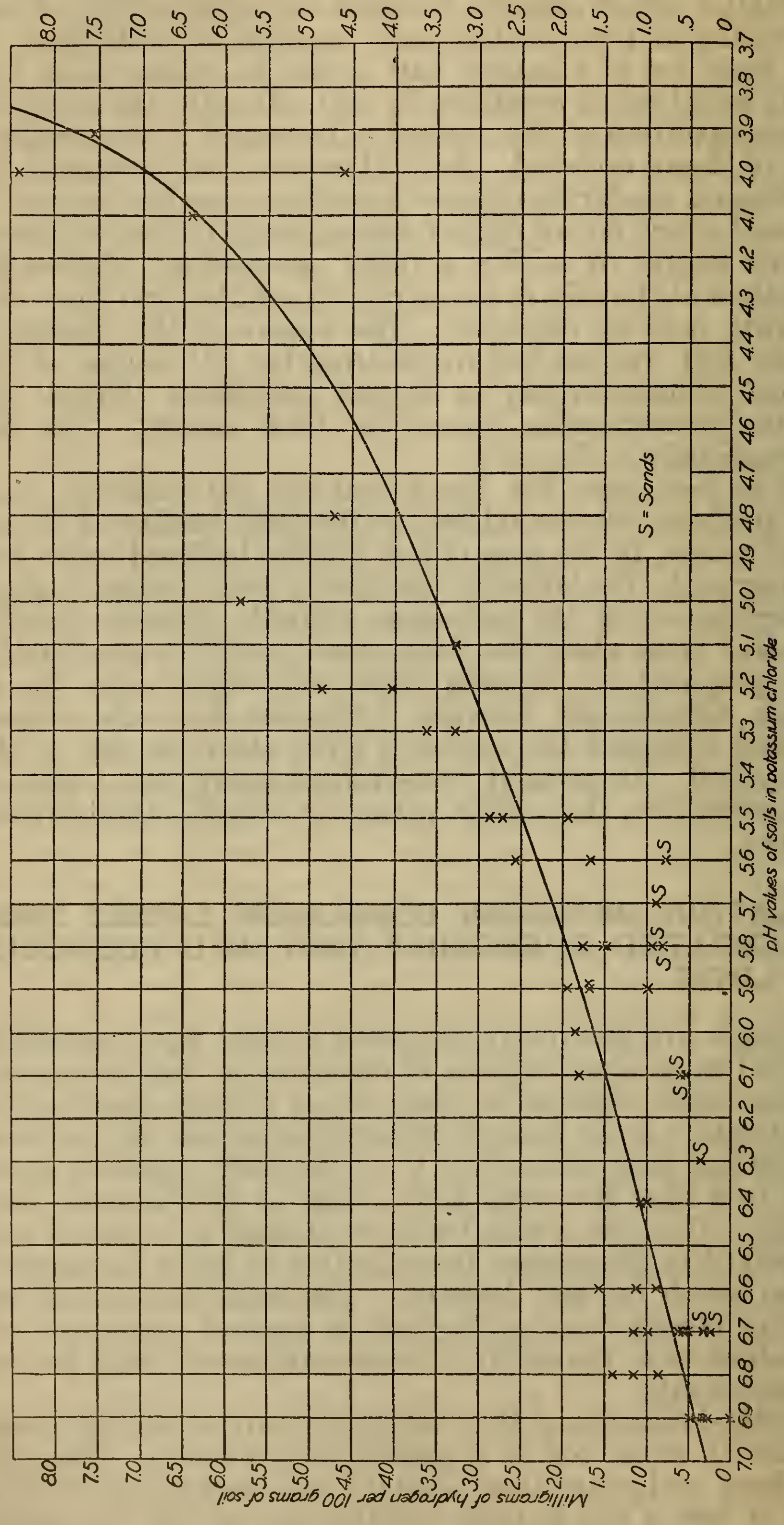

FIGURE 2.—*Relation between quantity of exchangeable hydrogen in soils and pH values of soils in potassium chloride*

quantity of distilled water. A second 10 g portion of soil was added, compacted, and moistened as before. The dish was then placed in a 500 ml (1-pint) preserving jar to which a small quantity of water had been added to maintain a saturated atmosphere, and the jar was sealed and kept at an average temperature of about 30° C. for two weeks. At the end of this period the disk was removed, washed thoroughly, and the rust removed by immersing the disk in a 10 per cent solution of ammonium citrate made alkaline with ammonia. The disk was allowed to remain 5 to 10 minutes in the solution at a temperature of 75° C. Rust which remained in pits was carefully removed by the point of a knife blade. The disk was then wiped dry and weighed. The rate of loss of weight was calculated as penetration in microns per day.

One of the most important factors to be controlled in carrying out the method is the moisture content of the soil, since preliminary studies showed that corrosion of the disks varied markedly with moisture content. In order that the degrees of corrosion caused by soils of different textures would be comparable, it was necessary to add to each soil an amount of water which was determined by the texture of the particular soil. The amount added was that given by the moisture equivalent, which is the percentage of water retained by a soil under a centrifugal force of 1,000 times the force of gravity. The physical significance of the moisture equivalent is that it represents the moisture-holding capacity of field soils when their moisture content is in equilibrium with gravitational and capillary forces. Owing to lack of suitable equipment, the values for the moisture equivalent were directly determined only for a representative group of the soils. In the case of the remaining samples this value was estimated for each soil on the basis of its texture.

In carrying out tests according to this method, a few special precautions were taken. The disks before being weighed were carefully cleaned with emery paper and then with a cloth moistened with ether. In order to avoid abnormal corrosive action from the rapid evolution of carbon dioxide as the result of bacterial activity, a small quantity of toluene was added to each sample. This precaution is probably necessary only in the case of soils containing considerable quantities of calcium carbonate and organic matter.

The data obtained from the accelerated test are shown graphically in Figure 3, together with the data on pipe replacements. It is apparent from the figure that the loss of weight values indicate fairly satisfactorily the corrosive areas except in the area between stake Nos. 26,000 and 31,000 in the soil mapped as Wauseon fine sandy loam. The failure of the accelerated test to indicate corrosiveness in this area may be explained by assuming that relatively coarse-textured soils with a given acidity do not corrode the metal disks to the same extent as heavy-textured soils, such as those of the Brookston and Nappanee series. A further illustration of this possibility is seen in the sandy loam soil at stake No. 100,500. In the presence of relatively high acidity, corresponding to 4.1 mg of hydrogen and pH 5.2 in potassium chloride, the metal disk has been corroded to only a slight extent, namely 1.1 per cent. The fact that the sandy loam soils referred to showed a marked tendency to preserve their state of aggregation when moistened suggests that this effect may also have tended to diminish their corrosive action in the accelerated test.

In order to study further the influence of the acidity and texture on the corrosion of the metal disks, the rates of penetration were plotted against the pH values of the soil samples in potassium chloride. The data are shown in Figure 4.

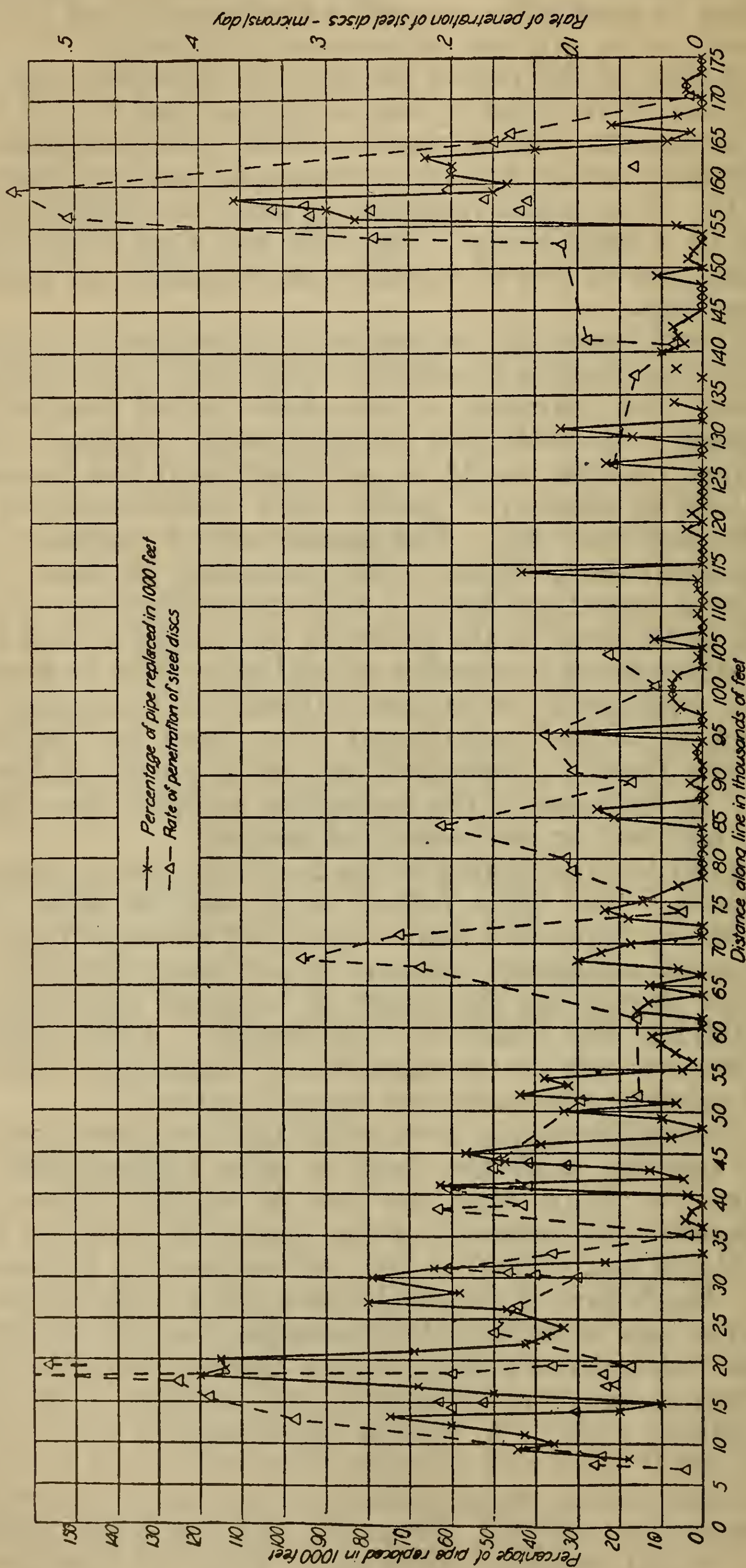

FIGURE 3.—*Comparison of rate of penetration of steel disks with quantity of pipe replaced in intervals of 1,000 feet*

In considering the figure it can be seen that a simple relation does not obtain between the values for rate of penetration and the pH values in potassium chloride. However, if the texture of the soils is considered, it can be seen that in the case of the fine-textured soils, namely, the clays and clay loams, a rough relation obtains between the rate of penetration and the pH values in potassium chloride; whereas in the case of the coarse soils, the sands and sandy loams, rate of penetration appears to be only slightly influenced by acidity. The distribution of the points between the two trend lines suggests that loss of weight of metal in soils of intermediate texture is influenced by acidity in proportion to the content of fine soil particles.

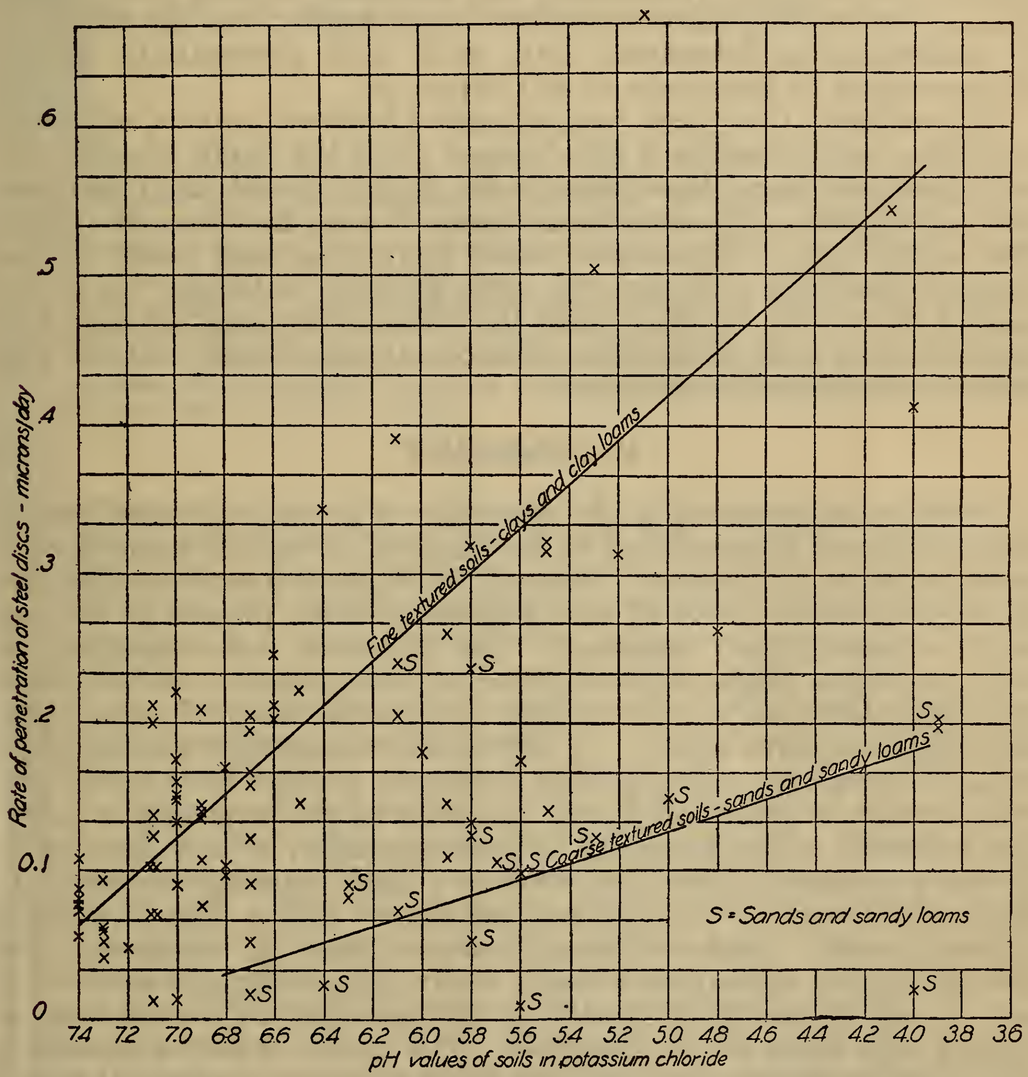

FIGURE 4.—*Relation between rate of penetration of steel disks in soils and pH values of soils in potassium chloride*

Although the acidity methods and the accelerated corrosion tests were equally satisfactory in indicating the corrosiveness of the heavy glacial soils, it has been seen that neither type of test was always dependable in the case of the coarser, sandy soils. It will be recalled that at stake No. 100,500 the acidity methods indicated corrosiveness although few if any replacements have been necessary in this area. Similarly, the loss-of-weight method proved inadequate in the corrosive area between stake Nos. 26,000 and 31,000. Since the soils at both of these locations are equally acid and of about the same texture, it is evident that a third factor in corrosion must be sought.

The essential difference between the corrosive and noncorrosive areas which are not well defined by the laboratory tests is one of drainage. In the noncorrosive area at stake No. 100,500 the soil is well drained. Between stake Nos. 26,000 and 31,000, however, the sandy loam soil overlies at about 30 inches glacial material of a peculiarly dense, compact nature. Owing to its impenetrability to water this material retards drainage to a considerable extent. The combination of the two factors—poor drainage and relatively high acidity—is probably responsible for corrosion in this area. This explanation of differences in corrosiveness emphasizes the necessity of supplementing laboratory data with field observations of soil characteristics in the study of soil corrosion.

The relations that have been observed between certain soil characteristics and corrosion were obtained from the study of soils that have developed in a limited area under similar conditions of temperature and rainfall. The conclusions reached may, therefore, be applied with safety only to those soils which have developed under similar climatic conditions and from the same geologic materials. It is reasonable to assume, however, that the correlations observed may also apply to other soils which differ from one another chiefly in their contents of exchangeable hydrogen.

V. SUMMARY

Corrosion experienced in the operation of a group of pipe lines in Ohio was found to be related to the kinds of soil which occur along a 32-mile section of the lines. Soils of the Brookston series in this area are noncorrosive. Soils of the Nappanee series proved to be corrosive wherever they occurred. The Wauseon soils occurring on slopes or slight ridges were observed to be corrosive. Other sandy and sandy-loam soils not underlain by glacial material apparently have little corrosive action. A satisfactory correlation was found to obtain between the exchangeable hydrogen present in the soils and corrosiveness as indicated by the quantity of pipe replaced in 1,000-foot intervals. The hydrogen ion concentration of soil samples in normal potassium chloride solution is a fairly satisfactory index to the corrosiveness of the soils studied except in the case of slightly buffered sands. Both methods, however, tend to exaggerate the corrosiveness of well-drained sandy soils. An accelerated laboratory test of soil corrosiveness involving the corrosion of a steel disk in contact with moist soil is described. The results obtained paralleled the quantity of pipe replacements fairly closely in the case of heavy soils. The degree of corrosiveness indicated by the test is influenced by the acidity, texture, and probably by the structure of the soils studied. Since only a qualitative study of the factors influencing the test has been made, the test can not at this time be considered a reliable index of soil corrosiveness except in the case of soils similar to those tested. The methods described for identifying corrosive soils which involve determinations of acidity are probably most reliable in the case of related soils which differ from one another chiefly in their contents of exchangeable hydrogen. The data obtained from the tests are probably insufficient to indicate the relative corrosiveness of soils having widely different physical and chemical characteristics.

WASHINGTON, June 17, 1931.